

I claim:

1. An adaptive optics control system for compensating distorted wavefronts each having a plurality of states including at least one of a velocity, intensities, phase slopes, and branch points, the system comprising:

5 a wavefront corrector having a surface controlled by a plurality of actuators;  
at least one wavefront sensor adapted to measure at least one state of the wavefront at a current point in time and to generate wavefront sensor output signals indicative of the at least one measured wavefront state; and  
a state space wavefront reconstructor adapted to receive the wavefront sensor output  
10 signals and generate a plurality of correction signals based thereon to be applied to the wavefront corrector.

2. The adaptive optics control system of claim 1, wherein the state space wavefront reconstructor comprises:

a state space wavefront estimator adapted to estimate a plurality of wavefront states at the  
15 current point in time; and

a wavefront phase reconstructor adapted to receive the wavefront state estimates, estimate a wavefront phase at the current point in time, and generate the plurality of correction signals based on the estimated wavefront phase.

3. The adaptive optics control system of claim 2, wherein the state space wavefront  
20 estimator is adapted to predict a plurality of wavefront states and wavefront sensor measurements at the current point in time based on the wavefront state estimates at a previous point in time, and wherein the wavefront state estimates are based on the predicted wavefront

states and the differences between the predicted wavefront sensor measurements and the measured wavefront states.

4. The adaptive optics control system of claim 2, wherein the state space wavefront estimator comprises a wavefront velocity estimator adapted to estimate the velocity of the wavefront at the current point in time.

5. The adaptive optics control system of claim 4, wherein the at least one wavefront sensor comprises at least one of a wavefront phase slope sensor adapted to measure the wavefront phase slopes of the wavefront and a wavefront intensity sensor adapted to measure the intensities of the wavefront.

6. The adaptive optics control system of claim 5, wherein the wavefront velocity estimated by the wavefront velocity estimator is based on at least one of the measured wavefront phase slopes and the measured wavefront intensities at the current point in time and at least one of the measured wavefront phase slopes and the measured wavefront intensities at a previous point in time.

7. The adaptive optics control system of claim 5, wherein the wavefront phase slope sensor and the wavefront intensity sensor are separate sensors.

8. The adaptive optics control system of claim 2, further comprising a wavefront velocity estimator adapted to estimate the velocity of the wavefront at the current point in time.

9. The adaptive optics control system of claim 8, wherein the at least one wavefront sensor comprises at least one of a wavefront phase slope sensor adapted to measure the wavefront phase slopes of the wavefront and a wavefront intensity sensor adapted to measure the intensities of the wavefront.

10. The adaptive optics control system of claim 9, wherein the wavefront velocity estimated by the wavefront velocity estimator is based on at least one of the measured wavefront phase slopes and the measured wavefront intensities at the current point in time and at least one of the measured wavefront phase slopes and the measured wavefront intensities at a previous point in  
5 time.
11. The adaptive optics control system of claim 9, wherein the wavefront phase slope sensor and the wavefront intensity sensor are separate sensors.
12. The adaptive optics control system of claim 1, further comprising a control system in communication with the wavefront corrector and adapted to condition the plurality of correction  
10 signals prior to them being applied to the wavefront corrector.
13. The adaptive optics control system of claim 12, wherein the control system is digital.
14. The adaptive optics control system of claim 12, wherein the control system is analog.
15. The adaptive optics control system of claim 3, further comprising memory adapted to store the measured wavefront states, the estimated wavefront states, the predicted wavefront  
15 states and the predicted wavefront sensor measurements.
16. The adaptive optics control system of claim 1, wherein the wavefront reconstructor further comprises at least one of a zero curl phase reconstructor and a non-zero curl phase reconstructor.
17. The adaptive optics control system of claim 16, wherein the zero curl reconstructor and  
20 the non-zero curl phase reconstructor comprise a single reconstructor.
18. The adaptive optics control system of claim 2, wherein the state space wavefront estimator comprises at least one processor and is implemented as a Kalman filter.

19. The adaptive optics control system of claim 2, wherein the state space wavefront estimator comprises at least one processor and is implemented as a statistically based algorithm.

20. A state space wavefront reconstructor for use in an adaptive optics control system for compensating distorted wavefronts, each wavefront having a plurality of states including at least one of a velocity, intensities, phase slopes and branch points, the system having a wavefront  
5 corrector and at least one wavefront sensor adapted to measure at least one state of the wavefront at a current point in time, the state space wavefront reconstructor comprising:

a state space wavefront estimator adapted to estimate a plurality of wavefront states at the current point in time; and

10 a wavefront phase reconstructor adapted to receive the wavefront state estimates, estimate a wavefront phase at the current point in time, and generate a plurality of correction signals based on the estimated wavefront phases, the correction signals for application to a wavefront corrector in communication with the state space reconstructor.

21. The state space wavefront reconstructor of claim 20, wherein the state space wavefront  
15 estimator is adapted to predict a plurality of wavefront states and wavefront sensor measurements at the current point in time based on the wavefront state estimates at a previous point in time, and calculate wavefront state estimates based on the predicted wavefront states and the differences between the predicted wavefront sensor measurements and the measured wavefront states.

20 22. The state space wavefront reconstructor of claim 20, further comprising a wavefront velocity estimator adapted to estimate the velocity of the wavefront at the current point in time.

23. The state space wavefront reconstructor of claim 22, wherein the at least one wavefront

sensor comprises at least one of a wavefront phase slope sensor adapted to measure the wavefront phase slopes of the wavefront at the current point in time and a wavefront intensity sensor adapted to measure the wavefront intensities of the wavefront at the current point in time.

24. The state space wavefront reconstructor of claim 23, wherein the estimated wavefront velocity is based on at least one of the measured wavefront phase slopes and the wavefront intensities at the current point in time and at least one of the measured wavefront phase slopes and measured wavefront intensities at a previous point in time.

25. The state space wavefront reconstructor of claim 23, wherein the wavefront phase slope sensor and the wavefront intensity sensor are separate sensors.

26. The state space wavefront reconstructor of claim 20, wherein the state space wavefront estimator comprises a wavefront velocity estimator adapted to estimate the velocity of the wavefront at the current point in time.

27. The state space wavefront reconstructor of claim 26, wherein the at least one wavefront sensor comprises at least one wavefront phase slope sensor adapted to measure the wavefront phase slopes of the wavefront at the current point in time, and a wavefront intensity sensor adapted to measure the wavefront intensities of the wavefront at the current point in time.

28. The state space wavefront reconstructor of claim 27, wherein the estimated wavefront velocity is based on at least one of the measured wavefront phase slopes and the measured wavefront intensities at the current point in time and at least one of the measured wavefront phase slopes and the measured wavefront intensities at a previous point in time.

29. The state space wavefront reconstructor of claim 27, wherein the wavefront phase slope sensor and the wavefront intensity sensor are separate sensors.

30. The state space wavefront reconstructor of claim 20, wherein the state space wavefront estimator comprises at least one processor and is implemented as a Kalman filter.

31. The state space wavefront reconstructor of claim 20, wherein the state space wavefront estimator comprises at least one processor and is implemented as a statistically based algorithm.

5 32. The state space wavefront reconstructor of claim 20, wherein the wavefront phase reconstructor comprises at least one of a zero curl phase reconstructor and a non-zero curl phase reconstructor.

33. The state space wavefront reconstructor of claim 32, wherein the zero curl phase reconstructor and the non-zero curl phase reconstructor comprise a single reconstructor.

10 34. The state space wavefront reconstructor of claim 21, further comprising a memory for storing the measured wavefront states, the estimated wavefront states, the predicted wavefront states, and the predicted wavefront state measurements.

35. A method of compensating for distortion of an optical wavefront using a state space wavefront reconstructor, the method comprising:

15 measuring at least one state of the wavefront with at least one wavefront sensor at a current point in time and generating wavefront sensor output signals indicative of the at least one measured wavefront state;

estimating a plurality of wavefront states at a current point in time;

estimating a wavefront phase at the current point in time based on the estimated

20 wavefront states; and

generating correction signals based on the estimated wavefront phase.

36. The method of claim 35, wherein the step of estimating comprises:

predicting a plurality of wavefront states and a plurality of wavefront state measurements at the current point in time based on the wavefront state estimates and the wavefront sensor measurements at a previous point in time.

37. The method of claim 36, wherein the estimated wavefront phase is based on the predicted wavefront states and the differences between the predicted wavefront sensor measurements and the measured wavefront states.

38. The method of claim 35, further comprising applying the plurality of correction signals to a wavefront corrector.

39. The method of claim 35, wherein the step of estimating the wavefront states comprises estimating at least one of a wavefront velocity, wavefront phase slopes, wavefront intensities and branch points.

40. The method of claim 35, wherein the step of estimating the wavefront states is performed through the use of a Kalman filter.

41. The method of claim 35, wherein the step of estimating the wavefront states is performed through the use of a statistically based algorithm.

42. The method of claim 35, wherein the at least one measured wavefront state comprises the wavefront intensities, wherein the step of estimating a plurality of wavefront states comprises estimating a wavefront velocity, and wherein the step of estimating the wavefront velocity comprises comparing the measured wavefront intensities at the current point in time with the measured wavefront intensities at a previous point in time.

43. The method of claim 35, wherein the at least one measured wavefront state comprises wavefront phase slopes, wherein the step of estimating a plurality of wavefront states comprises

estimating a wavefront velocity, and wherein the step of estimating the wavefront velocity comprises comparing the measured wavefront phase slopes at the current point in time with the measured wavefront phase slopes at a previous point in time.

44. The method of claim 35, wherein the at least one measured wavefront state comprises at least one of wavefront phase slopes and wavefront intensities, wherein the step of estimating a plurality of wavefront states comprises estimating a wavefront velocity, and wherein the step of estimating the wavefront velocity comprises comparing at least one of the measured wavefront phase slopes and the measured wavefront intensities at the current point in time with the at least one of the corresponding wavefront phase slopes and wavefront intensities at a previous point in time.

45. The method of claim 35, further comprising:

determining any covariances between the estimated wavefront states and the measured wavefront states; and

adjusting the wavefront state estimates based on the covariances.

46. The method of claim 35, further comprising conditioning the plurality of correction signals prior to their application to the wavefront corrector.